METHOD OF TRANSMITTING PILOT TONES IN A MULTI-SECTOR CELL, INCLUDING NULL PILOT TONES, FOR GENERATING CHANNEL QUALITY INDICATORS

RELATED APPLICATIONS:

The present application claims the benefit of U.S. Provisional Patent Application S.N. 60,449,729 filed February 24, 2003.

FIELD OF THE INVENTION:

The present invention is directed to wireless communications systems and, more particularly, to methods and apparatus for transmitting pilot signals in a multi-sector cell, e.g., a cell with synchronized sector transmissions.

BACKGROUND OF THE INVENTION:

In a wireless communications system, e.g. a cellular system, the channel conditions are an important consideration in the operation of the wireless system. Within a wireless communications system, a base station (BS) communicates with a plurality of wireless terminals (WTs), e.g., mobile nodes. As a wireless terminal moves to different locations within the base station's cell, the condition of the wireless communication channel between the base station and the wireless terminal may change, e.g., due to varying levels of noise and interference. The noise and interference experienced by the wireless terminal's receiver may include background noise, self-noise, and inter-sector interference. The background noise may be classified as independent from the base station's transmission power level. However, the self-noise and inter-sector interference are dependent on the base station's transmission power level, e.g. the transmission power in one or more sectors.

One method typically used to evaluate the condition of the communication channel is for the base station to transmit pilot signals, which are signals typically transmitted on a small fraction of the transmission resource and are generally comprised of known (pre-determined) symbols transmitted at a single constant power

36 level. The wireless terminal measures the pilot signals and reports to the BS in the

37 form of a scalar ratio such as signal-to-noise ratio (SNR) or an equivalent metric. In the

38 case where noise/interference is not dependent on the transmitted signal, e.g.,

39 background noise is predominant and the contribution from self-noise and inter-sector

40 interference is insignificant, such a single scalar metric is sufficient for the BS to predict

41 how the received SNR, at the wireless terminal, will change with signal transmit power.

42 Then, the base station can determine the minimum level of transmission power required

43 to achieve an acceptable received SNR at the wireless terminal, for the particular error-

44 correcting coding scheme and modulation used. However, in the case where the total

45 noise/interference includes a significant component that is dependent on signal

46 transmission power, e.g., inter-sector interference from base station transmissions in

47 adjacent sectors, the commonly used technique of obtaining an SNR from pilot signals

48 of one fixed strength level is insufficient. In such a case, the information obtained, e.g.,

49 SNR at a single transmission power level, by this commonly used technique, is

50 insufficient and inadequate for the BS to accurately predict the received SNR at the WT

51 as a function of the signal transmit power. Additional channel quality information needs

52 to be generated, collected by the wireless terminal, and relayed to the base station, so

53 that the base station can solve for the wireless terminals' function relating received

54 SNR to base station signal transmission power level. By obtaining such a function for a

55 wireless terminal's communication channel, the base station's scheduler, knowing the

56 acceptable level of received SNR for a particular coding rate, error-correcting code, and

57 modulation used, could efficiently assign a wireless terminal segments in a channel with

58 an appropriate power level, thus achieving acceptable SNR, limiting wasted

59 transmission power, and/or reducing overall levels of interference.

60

61   Based upon the above discussion, it is clear that there is a need, particularly in

62 the case of multi-sector wireless communications systems, for new and novel

63 apparatus and methods of channel quality measuring, evaluating and reporting that will

64 provide the base station with sufficient information to obtain the wireless terminal

65 received signal SNR as a function of base station transmitted power. In addition, to

66 support improved and/or more diverse channel quality measurements, new pilot signal

67 patterns, sequences and/or pilot signal transmission power levels which can facilitate

68 the analysis of self noise and interference form other sectors of a cell are desirable.

69

70 SUMMARY OF THE INVENTION:

71

72   Improved pilot signal sequences which facilitate multiple channel quality

73 measurements, e.g., through the use of different signal pilot transmission power levels,

74 are described. In various implementations the transmitted pilot sequences facilitate

75 determining the contribution of interference from other sectors of a cell using the same

76 tones, e.g., in a synchronized manner, as the sector in which the pilot signal

77 measurements are being made.

78

79   In cases where different sectors transmit on a tone at the same time using

80 approximately the same power, signals from other sectors while being interference can

81 be viewed as being similar or the same as self noise since transmission power affects

82 the amount of noise that will be encountered in a sector.

83

84   To measure noise contributions from neighboring sectors a sector NULL pilot,

85 e.g., a pilot with zero power, is transmitted in an adjacent sector at the same time a pilot

86 signal with a pre-selected, and therefore known, non-zero power is transmitted in the

87 sector where the received pilot signal measurement is made. To facilitate background

88 noise measurements, a cell NULL is supported in some embodiments. In the case of a

89 cell NULL, all sectors of a cell transmit a Null pilot, on a tone that is used to measure

90 background noise. Since no power is transmitted in the cell on the tone during the

91 measurement, any measured signal on the tone is attributable to noise, e.g.,

92 background noise which may include inter-cell interference.

93

94   The pilot sequences and signal measurements of the present invention provide

95 mechanisms that enable a wireless terminal (WT), and a BS that receives channel

96 condition feedback information from the WT, to predict downlink receive SNR for the

97 WT as a function of the signal transmit power in the presence of signal dependent

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98	noise. Feedback from individual WTs, in accordance with the invention, normally
99	includes at least two channel quality indicator values per WT, as opposed to a single
100	SNR value, where each of the two channel quality indicator values is generated using a
101	different function. One of the two channel quality indicator value generator functions
102	has a first pilot signal measurement corresponding to a received pilot signal having a
103	first known transmission power as an input. A second one of the two channel quality
104	indicator value generator functions has as an input a second pilot signal measurement
105	corresponding to another received pilot signal having a second known transmission
106	power which is different from the first known transmission power. Each of the first and
107	second channel quality indicator value generator functions, which may be implemented
108	as software modules or as hardware circuits, may also have additional inputs to those
109	just mentioned.
110	
111	Feedback from individual WTs, including at least two channel quality indicator
112	values per WT that are generated using different functions, enables the base station
113	(BS) to transmit to different WTs at different, e.g., minimum, signal powers depending
114	upon the respective SNRs required at the receivers. The total power transmitted by the
115	BS is typically known or fixed but the proportion allocated to different WTs may be
116	different and may vary over time. At a WT receiver, the dependence of total noise as a
117	function of the received signal power can be modeled by a straight line, referred to as
118	the 'noise characteristic line' in this invention. Since the noise characteristic line does
119	not in general go through the origin, a single scalar parameter is not enough to
120	characterize this line. At least two parameters are required to determine this line.
121	
122	The base station transmits pilot signals on the downlink. In accordance with the
123	invention, by transmitting pilot signals of different strength levels, the noise
124	characteristic line for the wireless terminal can be determined. In general a first pilot
125	signal is transmitted at a first power level to obtain a first point, and a second pilot
126	signal at a second power level, different from the first power level, is transmitted to
127	obtain a second data point. The second power level can be zero in some embodiments.

128 | The above pilot signal scheme can be used in a cell using an omni-antenna, that is, a
129 | cell with only one sector.
130 |
131 | The invention further determines SNR as a function of signal transmit power in a
132 | sectorized cellular environment. In one method of sectorization, each of the different
133 | sectors of a cell may use the entire or nearly the entire transmission resource (for
134 | example, frequency band) to transmit in each of the sectors. The total power
135 | transmitted from each sector is typically fixed or known, but different WTs may receive
136 | signal with different power. Since the isolation between the sectors is not perfect,
137 | signals transmitted on one sector may become noise (interference) to other sectors.
138 | Furthermore, if each of the sectors is constrained to transmit identical or nearly identical
139 | signal power (or to transmit signal power in a fixed proportion across the different
140 | sectors) on a given degree of freedom (e.g., time slot), the interference from other
141 | sectors to a WT in a given sector has the characteristics of signal-dependent noise or
142 | self-noise. This is particularly the case when the interference from other sectors scales
143 | with signal power which occurs in embodiment where different sectors are constrained
144 | to transmit identical or proportional power on a given degree of freedom, e.g., tones in
145 | an OFDM multiple access system.
146 |
147 | In accordance with the invention, regular pilots at different predetermined and
148 | known strength levels, are transmitted from the base station to the wireless terminals to
149 | characterize the dependence of total noise at a WT on the power of the signal by the
150 | BS to the WT. Different sectors may be, and often are, controlled to transmit at least
151 | some pilots on the same tone at the same time. Different sectors are often controlled to
152 | use different predetermined transmission power levels for the pilot signal transmitted on
153 | a tone in each of the sectors. For example, on tone 1 at time T1, a first sector may be
154 | controlled to transmit a pilot signal at a first power level while an adjacent sector is
155 | controlled to transmit at the same time T1, a pilot signal at a second power level on
156 | tone 1, the second power level being different from the first power level.
157 |

According to one embodiment of this invention, 'cell null pilots' are used in conjunction with regular pilots to characterize the dependence of total noise at a WT on the power of the signal transmitted by the BS to that WT. Cell null pilots are downlink resources (degrees of freedom) where none of the sectors of the cell transmit any power. Noise measured on these degrees of freedom provides an estimate of the signal-independent noise at the WT. Regular pilots (or simply pilots) are resources (degrees of freedom) where each sector of the cell transmits known symbols using fixed or predetermined powers. Noise measured on the pilots thus includes inter-sector interference and provides an estimate of the total noise, including signal-dependent noise.

One feature of the invention is directed to the concept of a 'sector null pilot'. The sector null pilots can be used in a sectorized cellular wireless system to estimate the noise at the WT, for example, when the WT is at the boundary of two sectors and the scheduling between the sectors is coordinated so that the WT at the boundary does not receive any interference from the other sector. Sector null pilot can be downlink resources where one sector in a cell does not transmit any signal energy and the rest or an adjoining sector transmits regular, e.g., non-zero pilots.

More generally, other types of sector null pilots can be defined, such as where a subset of the sectors of a cell transmits no signal on downlink resources and the remaining sectors transmit regular pilots. Also, more generally, the coordinated scheduling amongst the sectors can be such that the BS reduces (but does not necessarily eliminate) the transmit power on some sectors in order to reduce the interference that a WT receives from other sectors. In some cases, data is transmitted on a tone in an adjacent sector to a sector which transmits a pilot signal on the tone.

With the help of various regular strength pilots and/or various null pilot types, a WT can estimate the noise at the receiver as a function of the power of the signal transmitted to that WT under various conditions. The invention also concerns itself with the communication of this information from the WT to the BS in order to enable the BS

189   to determine the power to be used for transmitting to the different WTs in both omni-cell
190   and sectorized cell environments. Unlike prior art, the channel quality information is not
191   a single scalar value but includes two or more values which can be used to reflect the
192   effect of self noise and/or inter-sector noise in addition to background noise.

193

194   In an embodiment of the invention for an OFDM based cellular wireless system
195   the pilots include known symbols that are transmitted by the base station on specified
196   tones (and specified symbol times) at a fixed or predetermined power, and the null
197   pilots are typically tones that are left empty, i.e., with zero transmission power.

198

199   In an embodiment used in an omni-directional antenna deployment, known
200   herein as an "omni cell," the WT measures the SNR on the pilot tones, which includes
201   all noise/interference sources, including noise that is dependent on the pilot's transmit
202   power. In addition, the WT also measures the noise using the cell null pilot tone(s).
203   Taking the ratio of the received pilot power with this noise measurement gives an SNR
204   that is limited to signal-independent noise/interference. The WT transmits back to the
205   BS these two SNR values, or some equivalent combination of statistics.

206

207   In the embodiment of a sectorized deployment with directional sector antennas,
208   a single cell is divided into multiple sectors, some or all of which may be sharing the
209   same frequency band (degrees of freedom), corresponding to a frequency reuse of 1.
210   In this situation, in addition to the cell null pilot, the invention describes the use of sector
211   null pilots that are present in a subset of the sectors but not all sectors, and also gives a
212   pattern for pilot tones such that a null pilot tone in one sector is time/frequency
213   synchronized with a pilot tone in some or all of the other sectors. This allows the WT to
214   measure two or more signal-to-noise ratios, which include interference from different
215   combinations of sectors. On a reverse link, the WT reports a set of SNR-related
216   statistics, which enables the BS to make an estimate of these received SNR levels at a
217   WT as a function of the base station's transmit power. The BS uses the reported
218   channel quality values to determine the power level at which to transmit to achieve a
219   desired SNR at the WT.

220

221   In accordance with the invention, a wireless terminal makes measurements of at

222 least two different received pilot signals, which were transmitted at different first and

223 second pre-selected, and thus known, power levels. The two power levels may be,

224 e.g., a fixed non-zero power level and a transmission power level of zero although other

225 power level combinations are possible there being no mandatory requirement that one

226 power level be a zero power level. The value obtained from measuring the first

227 received pilot signal is processed by a first function to produce a first channel quality

228 indicator value. The second measured signal value obtained from measuring the

229 second received pilot signal is processed by a second function, which is different from

230 the first function, to produce a second channel quality indicator value. The first and

231 second channel quality indicator values are transmitted from the wireless terminal to the

232 base station. In some embodiments, they are transmitted in a single message while in

233 other embodiments they are transmitted in separate messages. The channel quality

234 indicator values may be, e.g., SNR values or power values. Thus, the first and second

235 channel quality indicator values may both be SNR values, may both be power values,

236 or one may be an SNR value and one a power value. Other types of values may also

237 be used as the channel quality indicator values with SNR and power values being

238 exemplary.

239

240   In some embodiments the WT determines its location relative to a sector

241 boundary and reports this location information to the base station. The location

242 information is reported to the base station. The reported location information is

243 normally in addition to the two channel quality indicator values is sometimes sent as a

244 separate message. However, in some cases, the location information is transmitted in

245 the same message as the two channel quality indicator values.

246

247   Numerous additional features, benefits and embodiments of the methods and

248 apparatus of the present invention are discussed in the detailed description which

249 follows.

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BRIEF DESCRIPTION OF THE DRAWINGS:

Figure 1 is a simplified diagram showing a transmitter and a receiver used for explaining the present invention.

Figure 2 shows an exemplary wireless cellular system.

Figure 3 shows an example where noise is dependent on transmitted signal power and is used for explaining the present invention.

Figure 4 shows an example of an exemplary noise characteristic line, showing received power vs total noise, and is used for explaining the present invention.

Figure 5 shows a graph of power vs frequency corresponding to an exemplary embodiment of the invention illustrating data tones, non-zero pilot tones, and a null pilot tone.

Figure 6 is a graph illustrating the relationship between SNR1, a wireless terminal received SNR including signal dependent and signal independent noise, and SNR0, a wireless terminals received SNR including no signal dependent noise for 3 cases: where noise is independent of the signal, where the signal dependent noise is equal to the signal, and where the signal dependent noise is less than the signal.

Figure 7 shows exemplary signaling for a three sector OFDM embodiment of the invention illustrating non-zero pilot tones, sector null pilot tones, and cell null pilot tones in accordance with the invention.

Figure 8 illustrates an example of tone hopping of the non-zero pilots, sector null pilot, and cell null pilots in accordance with the invention.

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281   Figure 9 illustrates three situations for an exemplary wireless terminal in a 3

282 sector embodiment used to explain the present invention in regard to the sector

283 boundary information aspects of the present invention.

284

285   Figure 10 illustrates a scheme using 3 sector types, which are repeated for the

286 cases with cells involving more than 3 sectors in accordance with the present invention.

287

288   Figure 11 illustrates an exemplary communications systems implementing the

289 present invention.

290

291   Figure 12 illustrates an exemplary base station implemented in accordance with

292 the present invention.

293

294   Figure 13 illustrates an exemplary wireless terminal implemented in accordance

295 with the present invention.

296

297   Figure 14 illustrates the steps of transmitting pilot tones in multiple sectors of a

298 cell in a synchronized manner in accordance with the present invention.

299

300   Figures 15-17 illustrate exemplary pilot tone transmissions along with pilot signal

301 transmission power information in accordance with the present invention.

302

303   Figure 18 illustrates a chart showing the transmission of signals on ten different

304 tones during a single symbol transmission period in accordance with the present

305 invention.

306

307   Figure 19 is a flowchart illustrating the operation of an exemplary wireless

308 terminal implementing the methods of the present invention.

309

310   Figure 20 is a flowchart illustrating the operation of an exemplary base station

311 implementing the methods of the present invention.

312

313	**DETAILED DESCRIPTION:**
314	
315	The methods and apparatus of the present invention are well suited for use in a
316	wireless communications system which uses one or more multi-sector cells. Figure 11
317	illustrates an exemplary system 1100 with a single cell 1104 shown but it is to be
318	understood that the system may, and often does, include many of such cells 1104.
319	Each cell 1104 is divided into a plurality of N sectors wherein N is a positive integer
320	greater than 1. System 1100 illustrates the case where each cell 1104 is subdivided
321	into 3 sectors: a first sector S0 1106, a second sector S1 1108, and a third sector S2
322	1110. Cell 1104 includes a S0/S1 sector boundary 1150, a S1/S2 sector boundary
323	1152, and a S2/S0 sector boundary 1154. Sector boundaries are boundaries where the
324	signals from multiple sectors, e.g., adjoining sectors, may be received at almost the
325	same level making it difficult for a receiver to distinguish between transmissions from
326	the sector in which it is located and the adjoining sector. In the cell 1104, multiple end
327	nodes (ENs), e.g., wireless terminals (WTs), such as mobile nodes, communicate with
328	a base station (BS) 1102. Cells with two sectors (N=2) and more than 3 sectors (N>3)
329	are also possible. In sector S0 1106, a plurality of end nodes EN(1) 1116, EN (X) 1118
330	are coupled to base station 1 1102 via wireless links 1117, 1119, respectively. In
331	sector S1 1108, a plurality of end nodes EN(1') 1120, EN (X') 1122 are coupled to base
332	station 1 1102 via wireless links 1121, 1123, respectively. In sector S2 1110, a plurality
333	of end nodes EN(1") 1124, EN (X") 1126 are coupled to base station 1 1102 via
334	wireless links 1125, 1127, respectively. In accordance with the invention, the base
335	station 1102 transmits pilot signals at multiple power levels to the ENs 1116, 1118,
336	1120, 1122, 1124, 1126, and there is synchronization of the transmission of pilot
337	signals of various predetermined and known levels between the three sectors. In
338	accordance with the invention, the end nodes, e.g., EN(1) 1116 report feedback
339	information, e.g., channel quality indicator values to the base station 1102, allowing the
340	base station 1102 to determine the wireless terminals received SNR as a function of
341	base station transmitted signal power. Base station 1102 is coupled to a network node
342	1112 via network link 1114. The network node 1112 is coupled to other network nodes,
343	e.g., intermediate nodes, other base station, AAA nodes, home agent nodes, etc., and

344 | the internet via network link 1129. Network node 1112 provides an interface outside
345 | cell 1104, so that ENs operating within the cell may communicate with peer nodes
346 | outside the cell 1104. The ENs within cell 1104 may move within the sectors 1106,
347 | 1108, 1110 of the cell 1104 or may move to another cell corresponding to another base
348 | station. Network links 1114 and 1129, maybe, e.g., fiber optic cables.
349 |
350 | Fig. 12 illustrates an exemplary base station (BS) 1200, implemented in
351 | accordance with the invention. Base station 1200 is a more detailed representation of
352 | base station 1102 shown in the exemplary communication system 1100 of Figure 11.
353 | The base station 1200 includes sectorized antennas 1203, 1205 coupled to receiver
354 | 1202 and transmitter 1204, respectively. The receiver 1202 includes a decoder 1212
355 | while the transmitter 1204 includes an encoder 1214. Base station 1200 also includes
356 | an I/O interface 1208, a processor, e.g., CPU, 1206 and memory 1210. The transmitter
357 | 1204 is used to transmit pilot signals into multiple sectors in a synchronized manner via
358 | sectorized transmit antenna 1205. The receiver 1202, the transmitter 1204, the
359 | processor 1206, the I/O interface 1208, and the memory 1210 are couple together via
360 | bus 1209 over which the various elements can interchange data and information. The
361 | I/O interface 1208 couples the base station 1200 to the Internet and to other network
362 | nodes.
363 |
364 | The memory 1210 includes routines 1218 and data/ information 1220. Routines
365 | 1218, which when executed by the processor 1206, cause the base station 1200 to
366 | operate in accordance with the invention. Routines 1218 include communications
367 | routine 1222, a received signal processing routine 1260, and base station control
368 | routines 1224. The received signal processing routine 1260 includes a channel quality
369 | indicator value extraction module 1262 which extracts channel quality indicator values
370 | from received signals, e.g., WT report messages, and a position information extraction
371 | module 1264 for extracting WT position information from received messages. The
372 | position information, in some embodiments, indicates a WT's position relative to a
373 | sector boundary. Extracted channel quality indicator values, e.g., SNR or power
374 | values, are provided to the transmission power calculation routine 1226 for use in

375 | calculating transmission power for signals transmitted to a WT. The base station
376 | control routines 1224 include a scheduler module 1225, a transmission power
377 | calculation routine 1226, and signaling routines 1228 including a pilot signal generation
378 | and transmission control routine.
379 |
380 | The data/information 1220 includes data 1232, pilot hopping sequence
381 | information 1234, and wireless terminal data / information 1240. Data 1232 may
382 | include data from the receiver's decoder 1212, data to be sent to the transmitter's
383 | encoder 1214, results of intermediate processing steps, etc. The pilot hopping
384 | sequence information 1234 includes power level information 1236 and tone information
385 | 1238. The power level information defines the different power levels that will be applied
386 | to different tones in order to generate pilots of various strengths, within the pilot tone
387 | hopping sequence in accordance with the invention. These pilot values are set e.g.,
388 | preselected fixed values, prior to transmission and are known to both the BS 1200 and
389 | WTs in the cell serviced by the BS 1200. Tone info 1238, includes information defining
390 | which tones shall be used as pilot tones of a specific strength level, which tones shall
391 | be sector null tones, and which tones shall be cell null tones, within the pilot tone
392 | hopping sequence for each sector for each terminal ID 1246. Wireless terminal
393 | data/information 1240 includes sets of data information for each wireless terminal
394 | operating within the cell, WT 1 info 1242, WT N info 1254. Each set of info, e.g., WT1
395 | info 1242 includes data 1244, terminal ID 1246, sector ID 1248, channel quality
396 | indicator values 1250, and sector boundary position info 1252. Data 1244 includes
397 | user data received from WT 1 and user data to be transmitted to a peer node
398 | communicating with WT 1. Terminal ID 1246 is a base station assigned Identification
399 | that has been assigned to WT 1; a specific pilot tone hopping sequence, including
400 | various strength pilot signals at predetermined times, is generated by the base station
401 | corresponding to each specific terminal ID 1246.
402 |
403 | The sector ID 1248 identifies which of the three sectors, S0, S1, S2, WT 1 is
404 | operating in. The channel quality indicator values 1250 include information conveyed
405 | by WT 1 to the base station in channel quality report messages, that the base station

406   may use to calculate the expected received WT1 SNR level as a function of base

407   station transmission signal power. The channel quality indicator values 1250 are

408   derived by WT1 from measurements performed by WT1 on the various strength pilot

409   signals transmitted by the base station, in accordance with the present invention. The

410   sector boundary position information 1252 includes: information identifying whether

411   WT1 has detected that it is near a sector boundary, experiencing high levels of

412   interference and information identifying which sector boundary WT1 is located near.

413   This information is obtained or derived from position feedback information transmitted

414   by the WT1 and received by the BS. The channel quality indicator values 1250 and the

415   sector boundary position information 1252 represent channel quality feedback

416   information from the WT1 to the base station 1200, providing information about one or

417   more downlink channels between the base station 1200 and WT1.

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419   Communications routines 1222 is used for controlling the base station 1200 to

420   perform various communications operations and implement various communications

421   protocols. Base station control routines 1224 used to control the base station 1200 to

422   perform basic base station functionality, e.g., signal generation and reception,

423   scheduling, and to implement the steps of the method of the present invention including

424   generation of pilot signals at different transmission strength levels, reception and

425   processing and use of wireless terminal reported information. The signaling routine

426   1228 controls the transmitter 1204 and the receiver 1204 which generate and detect

427   signals to and from the wireless terminals, e.g. OFDM signals following data tone

428   hopping sequences. Pilot signal generation and transmission control routine uses the

429   data/ information 1220 including the pilot hopping sequence info 1234 to generate a

430   specific pilot tone hopping sequences for each sector. The power levels of the pilot

431   tones, included in power level info 1236 and the specific tones selected to receive

432   specific pilot tones for each pilot in each sector at specific times are coordinated and

433   controlled under the direction of the pilot signal generation and transmission control

434   routine 1230. This routine 1230 controls the transmission of pilot tones, e.g., as

435   illustrated in Figs 15-17. Individual processing instructions, e.g., software commands,

436   responsible for the transmission of different pilot tones are individual components or

437	modules which may be interpreted as separate means which operate together to
438	control the base station to transmit the pilot tone sequences described and shown in
439	Figs. 15-17. Coordinating and/or synchronizing the transmission of various types of
440	pilot signals between the sectors of a cell, e.g., in terms of transmission frequency,
441	and/or symbol transmission time while controlling transmission power, enables a
442	wireless terminal receiving the various levels of transmitted pilot tones, e.g., known
443	predetermined fixed level pilot tones, sector null pilot tones, and cell null pilot tones, to
444	obtain, e.g., compute from measured signal values, channel quality indicator values
445	1250. In accordance with the invention, regular (non-null) pilot tones, sector null pilot
446	tones, and cell null pilot tones may punch through or replace data tones that would
447	normally be transmitted. Scheduling module 1225 is used to control transmission
448	scheduling and/or communication resource allocation. The scheduler 1225, in
449	accordance with the invention, may be supplied with information indicating each
450	wireless terminal's received SNR as a function of the base station transmitted signal
451	power. Such information, derived from the channel quality indicator values 1250, may
452	be used by the scheduler to allocate channel segments to WTs. This allows the BS
453	1200 to allocate segments on channels having sufficient transmission power to meet
454	received SNR requirements for a particular data rate, coding scheme, and/or
455	modulation selected to be provided to a WT.
456	
457	Figure 13 illustrates an exemplary wireless terminal 1300 implemented in
458	accordance with the present invention. The wireless terminal 1300 may be used as a
459	wireless end node, e.g., a mobile node. Wireless terminal 1300 is a more detailed
460	representation of the ENs 1114, 1116, 1118, 1120, 1122, 1124 shown in the exemplary
461	communications system 1100 of Figure 11. Wireless terminal 1300 includes a receiver
462	1302, a transmitter 1304, a processor, e.g., CPU, 1306, and memory 1308 coupled
463	together via a bus 1310 over which the elements may interchange data and
464	information. The wireless terminal 1300 includes receiver and transmitter antennas
465	1303, 1305 which are coupled to receiver and transmitter 1302, 1304 respectively. The
466	receiver 1302 includes a decoder 1312 while the transmitter 1304 includes an encoder
467	1314. Processor 1306, under control of one or more routines 1320 stored in memory

1308 causes the wireless terminal 1300 to operate in accordance with the methods of the present invention as described herein. Memory 1308 includes routines 1320 and data/information 1322. Routines 1320 includes communications routine 1324 and wireless terminal control routines 1326. The wireless terminal control routines 1326 includes signaling routine 1328 including a pilot signal measuring module 1330, a channel quality indicator value generating module 1332, a sector boundary position determining module 1331, and a channel quality indicator value transmission control module 1333. Data/information 1322 includes user data 1334, e.g. information to be transmitted from the wireless terminal 1300 to a peer node, user info 1336, and pilot signaling info 1350. User info 1336 includes measured signal values info 1337, quality indicator value information 1338, sector boundary position information 1340, terminal ID information 1342, base station ID information, and channel report information 1346. Pilot signaling info 1350 includes hopping sequence info 1352, power level info 1354, and tone info 1356. The measured signal value info 1337 includes measured signal values obtained from measurements, performed under the control of pilot signal measuring module 1330, of a at least one of an amplitude and phase of a received pilot signal. The quality indicator value information 1338 includes output from the channel quality indicator value generating module 1332. The channel quality indicator value information 1338, when transmitted to a base station may allow the base station to determine the WTs received SNR as a function of transmitted signal power. Sector boundary position information 1340 includes information identifying that the wireless terminal is in a sector boundary region, e.g., the wireless terminal is experiencing high inter-sector interference levels, and information identifying which of the two adjacent sectors is the boundary region sector. The base station may use the sector boundary information to identify channels in adjacent sectors where the transmission power should be turned off to reduce inter-sector interference. Channel report information 1346 includes the quality channel indicator values 1338 obtained or portions of the channel quality indicator values 1338 and may also include sector boundary position information 1340. The channel report information 1346 may be structured with individual messages for each quality indicator value or with groups of quality indicator values included in a single message. The messages may be sent out periodically at

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499 | predetermined times on dedicated channels. The terminal ID information 1342
500 | represents a base station assigned identification applied to the wireless terminal 1300
501 | while operating within the cellular coverage area of the base station. The base station
502 | ID info 1344 includes information specific to the base station, e.g., a slope value in a
503 | hopping sequence, and may also include sector identification information.
504 |
505 | The pilot hopping sequence information 1352 identifies for a given base station,
506 | with base station ID info 1344, which tones 1356 at what time, e.g., OFDM symbol time,
507 | should be measured to evaluate pilot signals. The pilot signal power level information
508 | 1354 identifies to the wireless terminals, the transmission levels of pilot signals on the
509 | assigned pilot signal tones 1356 included in the pilot tone hopping sequence 1352.
510 | Pilot signal power level information 1354 may also identify sector and cell null pilot
511 | tones.
512 |
513 | Communications routines 1324 is used for controlling the wireless terminal 1300
514 | to perform various communications operations and implement various communications
515 | protocols.
516 |
517 | Wireless terminal control routines 1326 controls the basic functionality of the
518 | wireless terminal 1300 in accordance with the methods of the present invention.
519 | Wireless terminal signaling routines 1328 control the basic functionality of the wireless
520 | terminal signaling including control of the receiver 1302, transmitter 1304, signal
521 | generation and reception and controls the operation of the wireless terminal in
522 | accordance with the methods of the present invention including the measuring of pilot
523 | signals, the generation of quality indicator values, and the transmission of channel
524 | quality indicator values. The pilot signal measuring module 1330 controls the
525 | measurement of received pilot signals, identified by the base station ID info 1344,
526 | hopping sequence info 1352, and tone info 1356. Pilot signal measuring routine 1330
527 | measures at least one of an amplitude and a phase of a pilot signal to produce a
528 | measured signal value corresponding to each pilot signal measured. Channel quality
529 | indicator value generating module 1332 includes a power estimation module 1361 and

530	a SNR estimation module 1362. Channel quality indicator value generating module
531	1332 generates quality indicator values according to functions, which use the measured
532	signal values 1337 output from the pilot signal measuring module 1330. Module 1332
533	includes first and second sets of instructions for implementing first and second channel
534	quality indicator value functions where the first and second functions are different.
535	Power estimation module 1361 includes software instructions for controlling the
536	processor 1306 to estimate the received power included in received pilot signal(s). SNR
537	estimation module 1362 includes software instructions for controlling the processor
538	1306 to estimate the signal to noise ratio of received pilot signal(s). The sector
539	boundary position determining module 1331 determines the position of the wireless
540	terminal 1300 relative to a sector boundary from information included in received
541	signals. The sector boundary position determining module 1331 may also distinguish
542	which adjacent sector boundary the wireless terminal is closer to and which adjacent
543	sector is causing higher interference levels with respect to WT 1300. The information
544	output from sector boundary position determining module 1131 is included in the sector
545	boundary position information 1340. The channel quality indicator value transmission
546	control routine 1333 controls the transmission of the quality channel value indicator
547	information and sector boundary information to the base station. The channel quality
548	indicator value transmission control routine 1333 includes a message generation
549	module 1335. Message generation module 1335 controls the processor 1306 using
550	machine executable instructions to generate messages used to communicate channel
551	quality indicator values. Message generation module 1335 may generate messages
552	with a single channel quality indicator value or include at least two channel quality
553	indicator values in a single message. Message generation module 1335 may also
554	generate messages, which include position information, e.g., sector boundary position
555	information 1340 or incorporate such information into a message which includes a
556	channel quality indicator value. The messages, generated by message generation
557	module 1335 are transmitted under control of the channel quality indicator value
558	transmission control module 1333. Messages corresponding to first and second values
559	may be interleaved, e.g., alternated for transmission purposes. Channel quality
560	indicator value transmission control module 1333 transmits messages periodically in

561 | some embodiments using communication channel segments dedicated to carrying

562 | channel quality indicator values. Module 1333 may also control the transmission times

563 | to correspond to pre-selected dedicated time slots dedicated by the base station for use

564 | by a WT 1300 thereby precluding other wireless terminals from using the dedicated

565 | time slots.

566 | .

567 | Figure 1 is a simplified diagram showing a transmitter 101 and a receiver 103

568 | which will be used for explaining the invention. Transmitter 101 may be, e.g., the

569 | transmitter 1204 of base station 1200, while receiver 103 may be, e.g., the receiver

570 | 1302 of wireless terminal 1300. In a communications system, such as the system

571 | 1100, the transmitter 101 often needs to make choices about the appropriate method

572 | for transmitting data to the receiver 103. The choices may include the code rate of the

573 | error-correcting code, the modulation constellation, and the transmit power level. In

574 | general, in order to make sensible choices, it is desirable for the transmitter 101 to have

575 | knowledge about the communication channel from the transmitter 101 to the receiver

576 | 103. Figure 1 shows an exemplary system 100, in which a transmitter 101 sends data

577 | traffic 104 to a receiver 103 on a forward link 105. On a reverse link 107 from the   Deleted: 102

578 | receiver 103 to the transmitter 101, the receiver 103 reports the forward link's channel

579 | condition 106 to the transmitter 101. The transmitter 101 then uses the reported

580 | channel condition information 106 to set its parameters properly for transmission.

581 |

582 | Figure 2 shows an exemplary wireless cellular system 200 where a transmitter is

583 | included in a base station (BS) 201 with antenna 205 and a receiver is included in a

584 | wireless terminal (WT), 203, e.g., a mobile terminal or a fixed terminal, with antenna

585 | 207, enabling the base station 201 to communicate information on the downlink

586 | channel(s) 208 to the wireless terminal 203. The BS 201 often transmits pilot signals

587 | 209, which are typically transmitted on a small fraction of the transmission resource and

588 | are generally comprised of known (pre-determined) symbols transmitted at a constant

589 | power. The WT 203 measures the downlink channel condition 213 based on the

590 | received pilot signals 209, and reports the channel conditions 213 to the BS 201 on an

591 | uplink channel 215. Note that since the channel conditions 213 often change over time

592	due to fading and Doppler effects, it is desirable that the BS 201 transmit the pilots 209
593	frequently or even continuously so that the WT 203 can track and report channel
594	conditions 213 as they vary with time. The WT 203 can evaluate the downlink channel
595	conditions 213 based on the received signal strength and the noise and interference on
596	the pilot signals 209. The combination of noise and interference will be referred to
597	subsequently as 'noise/interference' or sometimes just 'noise'. In the prior art
598	techniques, this type of information is normally reported in the form of a single scalar
599	ratio such as signal-to-noise ratio (SNR) or an equivalent metric. In the case where
600	noise/interference is not dependent on the transmitted signal, such a single scalar
601	metric is usually all that is required at the BS 201 to predict how the received SNR will
602	change with signal transmit power. In such a case, the BS 201 can determine the
603	correct (minimum) transmit power for the coding and modulation it selects to transmit
604	from the single received value. Unfortunately, in the multi-sector case, noise resulting
605	from transmitted signals can be a significant signal component making a single scalar
606	value insufficient for accurate SNR predictions for different transmission power levels.
607	
608	In many communication situations, especially in cellular wireless systems, such
609	as the multi-sector system 1100 of the invention, the noise is not independent of the
610	signal transmit power but depends on it. There is generally a component of noise
611	called 'self-noise', which is proportional or roughly proportional to the power of the
612	signal. Figure 3, shows an example where noise is dependent on signal transmit
613	power. In Figure 3, graph 300 shows received power of the signal of interest on the
614	vertical axis 301 vs total noise on the horizontal axis 303. Total noise, represented by
615	line 305 which is the sum of a signal dependent portion 309 and a signal independent
616	portion 307, is plotted against the received signal power 317. There may be many
617	reasons for the self-noise. An example of self-noise is the unequalized signal energy
618	that interferes with the received signal. This noise is proportional to the signal strength.
619	The unequalized signal energy could result from error in channel estimation or error in
620	the equalizer coefficients or from many other reasons. In situations where the self-
621	noise is comparable to or larger than the signal-independent noise, a single scalar
622	downlink SNR value (which may be measured on a pilot) is no longer adequate for the

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623 | BS 1200 to accurately predict the received SNR at the WT 1300 as a function of the
624 | signal transmit power.
625 |
626 | This invention provides a methods and apparatus which enable each WT 1300
627 | to predict its downlink receive SNR as a function of the signal transmit power in the
628 | presence of signal dependent noise 309 and communicate this information to the BS
629 | 1200. This enables the BS 1200 to transmit to different WTs at different (minimum)
630 | signal powers depending upon the respective SNRs required at each of the WTs. The
631 | total power transmitted by the BS 1200 is typically known or fixed but the proportion
632 | allocated to different WTs 1300 may be different and may vary over time. At a WT
633 | receiver 1302, the dependence of total noise 303 as a function of the received signal
634 | power 317 can be modeled by a straight line 305, referred to as the 'noise characteristic
635 | line' in this application, as shown in Figure 3. Since the noise characteristic line 305
636 | does not in general go through the origin, a single scalar parameter is not enough to
637 | characterize this line 305. At least two parameters, e.g., two channel quality indicator
638 | values, are required to determine this line 305. A simple method of determining this
639 | line is to identify the location of two distinct points, e.g., points 311 and 315, on it, since
640 | any two distinct points uniquely determine a straight line. Note that as a practical
641 | matter, the points can be determined with a limited accuracy, so that the accuracy with
642 | which the line is determined is better if the points are chosen farther apart than if the
643 | points are closer together.
644 |
645 | The base station 1200 transmits pilot signals on the downlink. In accordance
646 | with the invention, by transmitting pilot signals of different strength levels, the noise
647 | characteristic line for the wireless terminal can be determined. In general a first pilot
648 | signal is transmitted at a first power level to obtain a first point, and a second pilot
649 | signal at a second power level, different from the first power level, is transmitted to
650 | obtain a second data point. The first and second pilots can be transmitted at the same
651 | time if different tones are used for each pilot signal.
652 |

653   With respect to figure 3, the first pilot signal is measured and processed to

654   produce the first point 315 on line 305 identifying received pilot power level 317 and a

655   corresponding total noise level 319. In accordance with an embodiment of the

656   invention, the BS 1200 transmits 'null pilot' signals on the downlink in addition to non-

657   zero pilots. The null pilots are comprised of transmission resources (degrees of

658   freedom) where the BS 1200 transmits no signal power, e.g., transmits a pilot signal

659   having zero power. The second pilot signal, the null pilot signal, results in point 311 on

660   line 305 and identifies null pilot noise level 313 which is equivalent to the signal

661   independent noise 307. Based on the noise measured on both, the pilots and the null

662   pilots the WT 1300 obtains two different noise estimates 313, 315 at two different signal

663   powers, e.g., 0 power and received pilot power 317. From these two points 311, 315,

664   the WT 1300 can determine the entire noise characteristic line 305 of Figure 3. The

665   WT 1300 can then also communicate the parameters of this line 305 (for example,

666   slope and intercept, or some other equivalent set of information) to the BS 1200

667   enabling the BS 1200 to determine the received SNR for a given transmit signal power

668   when transmitting to the WT 1300 which reported multiple channel quality values.

669   Since null pilots have zero signal power and other pilots, on the other hand, are usually

670   transmitted at a relatively large power, the two points 311, 315 corresponding to the null

671   pilot and the non-zero pilot in Figure 3 are relatively far apart leading to a good

672   accuracy in characterizing the line 305.

673

674   Signal noise and various signaling issues will now be discussed further. Graph

675   400 of Figure 4 plots received power of a signal of interest on the vertical axis 401 vs

676   total noise on the horizontal axis 403. Figure 4 gives an illustration of an exemplary

677   noise characteristic line 405. To characterize the line 405, in accordance with the

678   invention, the BS 1200 transmits signals that enable the WT 1300 to make

679   measurements of at least two distinct points on the line, e.g. points 407 and 409,

680   information, characterizing the line 405, obtained from those measurements is then

681   transmitted to the BS 1200. For example, the BS 1200 can transmit two different signal

682   powers $P1$ and $P2$ that will be received as powers $Y1$ and $Y2$ as shown in Figure 4.

683   The WT 1300 measures the corresponding received signal powers, denoted as $Y1$, 415

684 | and Y2 419, and the corresponding total noise, denoted as X1 413 and X2 417,

685 | respectively. From X1 413, X2 417, Y1 415, and Y2 419, the slope and the intercept of

686 | the line 405 can be uniquely determined. In one embodiment, P1 and P2 are known

687 | and fixed. In another embodiment, P2 can be the pilot power, corresponding to a pilot

688 | signal, while P1 can be zero, representing a null signal, which occupies some

689 | transmission resource but with zero transmission power. In general, however, P1 does

690 | not necessarily have to be zero. For example, P1 can and in some embodiments is

691 | some positive number smaller than P2.

692 |

693 | Once the noise characteristic line 405 has been determined by the BS 1200 from

694 | received feedback information, the BS 1200 can calculate the SNR at the WT receiver

695 | 1302 for any given transmission power Q. For example, Figure 4 shows the procedure

696 | of determining the SNR corresponding to a given transmission power Q. First, the BS

697 | 1200 finds the corresponding received signal power Y 421 of transmission power Q, by

698 | linearly interpolating between the points (Y2, P2) and (Y1, P1):

699 |

700 | $$Y = Y1 + \frac{Y2 - Y1}{P2 - P1} \cdot (Q - P1).$$

701 |

702 | The corresponding noise power corresponding to a transmission power Q is given by

703 | linearly interpolating between the points (X2, P2) and (X1, P1):

704 |

705 | $$X = X1 + \frac{X2 - X1}{P2 - P1} \cdot (Q - P1)$$

706 |

707 | Then SNR(Q), the SNR as seen by the WT 1300 for a BS transmit power Q, is given

708 | by:

709 |

710 | $$SNR(Q) = \frac{Y}{X} = \frac{Y1(P2 - P1) + (Y2 - Y1)(Q - P1)}{X1(P2 - P1) + (X2 - X1)(Q - P1)}$$

711 |

712 Point A 411 on the noise characteristic line 405 shown in Figure 4 has the x-axis value

713 of X 420 and y-axis value of Y 421 and corresponds to transmission power Q. Note the

714 slope of a line that connects point A 411 and the origin 422 is $SNR(Q)$, the SNR at the

715 WT receiver 1302 if transmit power Q is used. Therefore, from the noise characteristic

716 line 405 generated from the reported statistics from the WT 1300, the BS 1200 can and

717 does determine, for example, what transmission power is required to meet a given SNR

718 requirement for the WT 1300.

719

720 Figure 5 shows a graph 500 plotting power on the vertical axis 501 vs frequency

721 on the horizontal axis 503. Figure 5 corresponds to one exemplary embodiment of this

722 invention, in which the wireless cellular network uses Orthogonal Frequency Division

723 Modulation (OFDM). In this exemplary case, the frequency 505 is divided into 31

724 orthogonal tones, such that transmissions on different tones do not interfere with each

725 other at the receiver, even in the presence of multipath fading in the channel. The

726 minimum unit of signal transmission is a single tone in an OFDM symbol, which

727 corresponds to a combination of time and frequency resources.

728

729 Figure 5 shows the power profile of the tones at a given OFDM symbol. In this

730 embodiment, a pilot 515 is a known symbol sent at a fixed pilot power 507 on a tone,

731 and the null pilot 513 is a tone with zero transmission power. These pilot tones 515 and

732 null pilot tones 513 may hop over time, meaning that from one OFDM symbol to the

733 next, the position that they occupy may vary. Over extended periods of time, the pilot

734 signal transmissions are periodic due to the repetition of the hopping sequences. Four

735 pilot tones 515 and one null pilot tone 513 are shown in Figure 5. The tone locations of

736 the pilots 515 and the null pilots 513 are known to both the BS 1200 and the WT 1300.

737 Twenty-six data tones 511 are also shown in Figure 5 with corresponding transmission

738 power level 509. Figure 5 illustrates that the pilot tone transmission power level 515 is

739 significantly higher than the data tone transmission power level 509, allowing the

740 wireless terminals to easily recognize pilot tones. In general, the data tone

741 transmission power 509 may not necessarily be the same across all the data tones as

742 shown in Figure 5, but level 509 may vary from data tone to data tone.

In the situation of a wireless deployment situation deployed with omni-directional antennas, the embodiment specifies a single null pilot known as the cell null pilot. Suppose that a pilot tone is transmitted at power P, and a tone carrying data traffic 211 is transmitted at power Q, as indicated in Figure 5. By looking at the received signal for the pilot, the WT 1300 is able to measure the SNR, which we refer to as $SNR(P)$. The goal is for the base station 1200 to be able to obtain an estimate of $SNR(Q)$, which is the SNR as seen by the wireless terminal 1300 corresponding to the base station's transmission of data at power Q, which may be different from P.

The knowledge of the received SNR is important since it determines the combination of coding rates and modulation constellations that can be supported. For a specified target block error rate (e. g., the probability that the transmission of a single codeword is incorrect) and for each coding rate and modulation constellation, it is possible to define a minimum SNR that the received SNR must exceed in order for the probability of unsuccessful transmission to be less than the specified target rate (e.g., 1% block error rate). From this point of view, it is desirable for the BS 1200 be able to accurately estimate $SNR(Q)$ in order to solve for the transmit power Q that will produce an SNR that exceeds the minimum SNR for the desired code rate and modulation constellation.

The relationship between $SNR(Q)$ and Q depends on the signal-dependent noise. For the sake of description, we assume that the signal-dependent noise is proportional to the transmit power and use the noise characteristic line 305, 405 as shown in Figures 3 and 4 to characterize the dependence of the total noise as a function of the received signal power. The principle can similarly be extended to other situations.

Let α denote the channel gain, so that when the BS transmits at power P, the received power by wireless terminal is αP. Let N denote the signal-independent noise,

and γP represent the signal-dependent noise, where γ is the proportionality factor to the transmit power P. Then when measuring the SNR on pilot tones, the WT 1300 measures an SNR of

$$SNR1(P) = \frac{\alpha P}{N + \gamma P},$$

where P is the constant transmit power of the pilots and N is the signal-independent noise seen by the WT 1300. We call this 'SNR1' to indicate that it treats the signal-dependent interference as a single entity.

By using the null pilot, it is possible for the WT 1300 to separately measure the signal-independent noise N, since there is no power transmitted by the BS 1200 on this null tone. By comparing this signal-independent noise N with the received power αP of the BS pilot, it is possible to estimate an SNR that is free of signal-dependent noise. Let us represent this ratio by $SNR0(P) = \frac{\alpha P}{N}$, where the name 'SNR0' indicates that it considers no signal-dependent noise. Then the relationship between SNR1(P) and SNR0(P) is given by:

$$\frac{1}{SNR1(P)} = \frac{1}{SNR0(P)} + \frac{\gamma}{\alpha}.$$

For notational simplicity, let us define

$$SRR1 = \frac{\gamma}{\alpha}.$$

Comparing with the noise characteristic line shown in Figures 3 and 4, one can see that SNR0(P) corresponds to the x-axis intercept of the line, while SRR1 is equivalent to the slope of the line. Then as a function of SNR0(P) and SRR1, we can write:

800

801
$$SNR1(P) = \frac{SNR0(P)}{SRR1 \cdot SNR0(P) + 1} \, .$$

802

803 In an embodiment, the measurements SNR0(P) and the SRR1 are reported by the WT

804 1300 to the BS 1200. From these reports, the BS 1200 can compute SNR1(P).

805

806   Graph 600 of Figure 6 illustrates the relationship between SNR1(P) on the

807 vertical axis 601 and SNR0(P) on the horizontal axis 603, where the SNRs are plotted

808 in dB. Three curves illustrates by lines 605, 607, and 609 representing SRR1=0,

809 SRR1=0.5, and SRR1=1, respectively. The case of SRR1=0 (line 605) corresponds to

810 the situation where noise is independent of the signal, so that SNR1(P)=SNR0(P). The

811 case of SRR1=1 (line 609) corresponds to the case where the signal-dependent noise

812 is equal to the signal so that it is never possible for SNR1(P) to exceed 0 dB.

813

814   From the information received from the WT 1300, the BS 1200 can then

815 compute the received SNR as a function of the transmit power Q for the data traffic.

816 The received SNR by the WT 1300 will include signal-dependent noise, and takes the

817 form

818

819
$$SNR1(Q) = \frac{\alpha Q}{N + \gamma Q} \, .$$

820

821 Inverting and performing substitutions gives:

822

823
$$\frac{1}{SNR1(Q)} = \frac{N}{\alpha Q} + \frac{\gamma}{\alpha} = \frac{1}{SNR0(P)}\frac{P}{Q} + SRR1$$

$$SNR1(Q) = \frac{SNR0(P)}{SNR0(P) \cdot SRR1 + \dfrac{P}{Q}}$$

824

825   Hence as a function of the values $SNR0(P)$ and $SRR1$ reported by the WT 1300,

826   it is possible to predict the SNR as seen by the WT 1300 for any transmit power Q.

827   These derivations illustrate that using the null pilot, the WT 1300 can determine and

828   transmit statistics to the BS 1200 which enable the BS 1200 to predict SNR as a

829   function of transmit power in the presence of signal-dependent noise that is proportional

830   to the transmit power.

831

832   Note that rather than sending $SNR0(P)$ and $SRR1$, there are other equivalent

833   sets of reports that the WT 1300 can send to the BS 1200, which fall within the scope of

834   the invention.

835

836   The methods and apparatus of the present invention are particularly useful in a

837   multi-sector cell. In wireless cellular systems, base stations 1200 are often deployed in

838   a configuration where each cell is divided into multiple sectors as shown in Figure 11.

839   For a sectorized environment, the interference between sectors 1106, 1108, 1110 has a

840   significant impact on the received SNR. In addition to the signal-independent portion,

841   the total noise also includes signal-dependent portions, each of which is proportional to

842   the signal power from other sectors of the same cell 1104. The noise characteristics in

843   this case are more complex than what is shown in Figure 3, because in this sectorized

844   situation, the total noise includes two or more signal-dependent components instead of

845   one. However, the total noise can still be characterized by a straight line, which is now

846   defined in a higher dimensional space. This noise characteristic line can be described,

847   for example, by an intercept and slopes. The intercept is a function of the signal-

848   independent noise portion and each slope corresponds to the proportionality of the

849   signal-dependent noise portion with respect to a particular signal power.

850

851   In certain scenarios, however, the description of the noise characteristic line can

852   be simplified. For example, in an exemplary method of sectorization, where the each of

853   the sectors of a cell may use the entire or nearly the entire transmission resource, e.g.,

854   frequency band, to transmit in each of the sectors. The total power transmitted from

855   each sector is typically fixed or known but different WTs 1300 may receive a different

856	fraction of it. Since the isolation between the sectors is not perfect, signal transmitted
857	on one sector becomes noise (interference) to other sectors. Furthermore, if each of
858	the sectors 1106, 1108, 1110 is constrained to transmit identical, proportional or nearly
859	proportional signal power on a given degree of freedom, the interference from other
860	sectors to a WT 1300 in a given sector 1106, 1108, 1110 appears like signal dependent
861	noise or self-noise. This is the case because the interference from other sectors scales
862	with signal power, so that the noise characteristic line is similar to what is shown in
863	Figure 3.
864	
865	In accordance with the invention, the BS 1200 transmits signals such as the 'cell
866	null pilot' that enable the WT 1300 to evaluate the intercept of the noise characteristic
867	line with all of the signal-independent noise. In addition, as an example, the scheduling
868	amongst the sectors 1106, 1108, 1110 may be coordinated so that WTs 1300 at the
869	boundary 1150, 1152, 1154 of sectors do not receive any interference (or receive
870	reduced interference) from other sectors. In accordance with the invention, the BS
871	1200 transmits signals such as the 'sector null pilot' that enable the WT 1300 to
872	evaluate the slope of the noise characteristic line taking into account only the signal-
873	dependent noise from a subset of sectors. In accordance with the invention, the WT
874	1300 then reports the signal-independent SNR and these different slopes, or some
875	equivalent set of information, back to the BS 1200 on a reverse link.
876	
877	Figure 7 shows in diagram 700 the signaling for an embodiment of the invention
878	in the case of a sectorized cellular wireless system using Orthogonal Frequency
879	Division Modulation (OFDM). Consider a BS 1200 with three sectors 701, 703, 705, in
880	which the same carrier frequency is reused in all sectors 701, 703, 705. The pilot
881	power level corresponding to sectors 701, 703, 705 are indicated by reference numbers
882	709, 713 and 717, respectively. Data signal power levels are indicated by reference
883	numbers 711, 715, 719 for each of the first through third sectors, respectively. The
884	situation of other numbers of sectors will be discussed below. Let the three sectors
885	1106, 1108, 1110 of the base station 1200 be represented by S0 701, S1 703, and S2
886	705 as shown in Figure 7. Figure 7 shows a tone allocation for the downlink

887 | transmission at a given OFDM symbol 707, including an example of the placement of

888 | data tones, e.g. exemplary data tone 728, pilot tones, e.g. exemplary pilot tone 727,

889 | and null pilot tones, e.g. exemplary null pilot tone 721, across the three sectors. Since it

890 | is assumed that each of the sectors share the same frequency band, the corresponding

891 | tones between sectors will interfere with each other. Note that the position and order of

892 | the tones are shown for illustrative purposes only and may vary in different

893 | implementations.

894 |

895 | In accordance with the invention, the downlink signal includes one or more cell

896 | null pilots, which are null tones that are shared by each of the sectors 701, 703, 705. In

897 | a cell null pilot 729, there is zero transmission power in each of the sectors 701,703,

898 | 705. In addition, the downlink signal includes one or more sector nulls 721, 723, 725

899 | where the transmission power is zero only in a subset of the sectors 701, 703, 705. In

900 | the same tone as the sector null pilot, it is desirable to have a pilot tone or a data tone

901 | whose transmission power is fixed and known to the WT 1300 in the other sectors. For

902 | example, sector S1 703 sector null pilot 723, has corresponding sector S0 701 pilot

903 | tone 731 and corresponding sector S2 705 pilot tone 737.

904 |

905 | In one embodiment shown in Figure 7, there are 4 pilots, 1 sector null pilot and 1

906 | cell null pilot in each sector 701, 703, 705. For example, sector S0 701 has four pilots

907 | 731, 733, 735, 737, one sector null pilot 721, and one cell null pilot 729. These pilots

908 | are arranged such that each sector has two unique pilots, and then shares a pilot with

909 | each of the two other sectors. For example, sector S0 701 has unique pilots 735, 727;

910 | pilot 731 shares a tone frequency with pilot 737 of sector S2 705; pilot 733 shares a

911 | tone frequency with pilot 739 of sector S1 703. In addition, the sector null pilot for one

912 | sector coincides with pilot tones in the other sectors. For example, for the null tone 725

913 | in sector S2 705, a pilot 733, 739 is transmitted on the same tone in sectors S0 701 and

914 | S1 703, respectively. The locations of the pilot tones, the cell null tones and the sector

915 | null tones are known to both the BS 1200 and the WT 1300.

916 |

917   The pilots change their positions, or 'hop,' over time for various reasons such as

918 frequency diversity. Figure 8 gives an example of the tone hopping of the pilots, cell

919 null pilots, and sector null pilots. Graph 800 of Figure 8 plots frequency on the vertical

920 axis 801 vs time on the horizontal axis 803. Each small vertical subdivision 805

921 corresponds to a tone, which each small horizontal subdivision 807 corresponds to an

922 OFDM symbol time. Each pilot tone 809 is represented by a small box with vertical

923 shading. Each sector null pilot 811 is represented by a small box with horizontal line

924 shading. Each cell null pilot 813 is represented by a small box with cross hatched

925 shading.

926

927   In an embodiment, the pilot tones essentially hop following a modular linear

928 hopping pattern. In accordance with the invention, the sector null tones hop following

929 the same modular linear pattern as the pilot hopping with the same slope value.

930 Moreover, in one embodiment of the invention, the cell null pilot tones also hop

931 following the same modular linear pattern as the pilot hopping with the same slope

932 value.

933

934   In an embodiment, the data tones essentially hop following a permuted modular

935 linear hopping pattern. In another embodiment of the invention, the cell null pilots hop

936 following the same permuted modular linear pattern as the data hopping. In that

937 embodiment, when a cell null pilot tone collides with a pilot tone, either the transmission

938 of the pilot tone in each of the sectors is suspended and the pilot tone is effectively

939 erased, or the transmission of the pilot tone continues in at least some of the sectors

940 and the cell null pilot tone is effectively rendered unusable.

941

942   Suppose that the WT 1300 has a link established with sector S0 of the base

943 station 1200, and that the channel gain from S0 to WT 1300 is given by α. Similarly,

944 suppose that the channel gain from S1 to WT 1300 is given by β, and from S2 to WT

945 1300 is given by γ. Finally for completeness, suppose that the signal-dependent noise

946 in the link from S0 to WT 1300 includes self-noise that is proportional to the transmit

947 power with a channel gain of δ.

948

949   Suppose that the transmit power for the data tones on the three sectors is given

950 by $Q0$, $Q1$, and $Q2$, respectively. Then the received SNR for the link from S0 to WT

951 1300 is given by

952

953
$$SNR_{S0}(Q0,Q1,Q2) = \frac{\alpha Q0}{\delta Q0 + \beta Q1 + \gamma Q2 + N}.$$

954

955   For the remainder of this discussion, it will be assumed that the interference due

956 to the other sectors ($\beta Q1$ and $\gamma Q2$) is much more significant than the signal-dependent

957 noise from the same sector $\delta Q0$, so that for simplicity this term will be omitted in the

958 subsequent discussion.

959

960   The WT 1300 should provide a set of parameters to the base station so that it

961 has enough information to predict the received SNR for the downlink data transmission

962 from S0 to WT 1300. To obtain that information, it may use the null pilot tones. Using a

963 cell null pilot, in which the transmission in each of the sectors is 0, it is possible to

964 measure the signal-independent noise. Comparing that with the received strength of

965 the pilot from S0 gives the following SNR:

966

967
$$SNR0(P) = \frac{\alpha P}{N}$$

968

969   Next, the sector null pilot tones can be, and in various embodiments are, used to

970 measure the SNR in the situation when one of the neighboring sectors is not

971 transmitting. In particular, for sector S0, consider the pilot tone that corresponds to a

972 sector null pilot tone in S2. Then measuring the SNR based on this pilot in sector S0

973 will give the value

974

975

$$SNR1^{\beta}(P) = \frac{\alpha P}{\beta P + N},$$

976

977 where the interfering sector is S1 (with path gain β). Similarly, by measuring the SNR

978 on the pilot tone that is a sector null tone in S1, the interfering sector is sector S2 (with

979 path gain γ), and the resulting SNR is given by

980

981

$$SNR1^{\gamma}(P) = \frac{\alpha P}{\gamma P + N}.$$

982

983 The slopes of the noise characteristic line in these two cases are $\frac{\beta}{\alpha}$ and $\frac{\gamma}{\alpha}$,

984 respectively.

985

986   Next, if the SNR is directly measured using pilot tones that do not correspond to

987 sector null pilots in the other sectors, then this SNR measurement takes into account

988 the interference from the other two sectors. This measurement is called SNR2, since it

989 includes interference from two sectors.

990

991

$$SNR2(P) = \frac{\alpha P}{\beta P + \gamma P + N}$$

992

993 The slope of the noise characteristic line in this case is $\frac{\beta + \gamma}{\alpha}$.

994   .

995   By defining the following SRR as proper slope values of the noise characteristic

996 lines, it is possible to relate $SNR1^{\beta}(P)$, $SNR1^{\gamma}(P)$, and SNR2(P) to SNR0(P):

997

-35-

$$SRR2 = \frac{\beta + \gamma}{\alpha}$$

998

$$SRR1^\beta = \frac{\beta}{\alpha}$$

$$SRR1^\gamma = \frac{\gamma}{\alpha}$$

999

1000   The SRRs themselves can be computed in terms of the SNRs as follows:

1001

$$SRR2 = \frac{1}{SNR2(P)} - \frac{1}{SNR0(P)}$$

1002

$$SRR1^\beta = \frac{1}{SNR1^\beta(P)} - \frac{1}{SNR0(P)}$$

$$SRR1^\gamma = \frac{1}{SNR1^\gamma(P)} - \frac{1}{SNR0(P)}$$

1003

1004   Note that SRR2 can be found as the sum of $SRR1^\beta$ and $SRR1^\gamma$.

1005

1006   Then the SNRs can be written in terms of SNR0(P) and the SRRs:

1007

1008

$$SNR2(P) = \frac{SNR0(P)}{1 + SRR2 \cdot SNR0(P)}$$

1009

$$SNR1^\gamma(P) = \frac{SNR0(P)}{1 + SRR1^\gamma \cdot SNR0(P)}$$

1010

$$SNR1^\beta(P) = \frac{SNR0(P)}{1 + SRR1^\beta \cdot SNR0(P)}$$

1011

1012   If the WT 1300 reports a sufficient set of these statistics (e.g.,

1013 $SNR0(P), SRR1^\beta, SRR1^\gamma, SRR2$) to the base station 1200, the base station 1200 can

1014   predict the received SNR by the WT 1300 based on the transmit powers Q0, Q1, and

1015   Q2. In general, the SNR as seen by the WT 1300 for a data transmission with power

Q0, with interference from sectors S1 and S2 with powers Q1 and Q2, is given in terms

of the measurements made on the pilot tone with transmit power P as:

$$SNR_{s0}(Q0,Q1,Q2) = \frac{\alpha Q0}{\beta Q1 + \gamma Q2 + N}$$

$$= \frac{SNR0(P)}{\left(\frac{Q1}{Q0}SRR1^{\beta} + \frac{Q2}{Q0}SRR1^{\gamma}\right) \cdot SNR0(P) + \frac{P}{Q0}}$$

In Figure 9, diagram 900 shows three situations for an exemplary WT in sector S0. Cell 901 includes three sectors S0 903, S1 905, and S2 907. Fig 9 shows a WT 909 near the boundary with sector S1 905, where WT 909 receives significant downlink interference from sector S1 905. Cell 921 including three sectors S0 923, S1 925, and S2 927 shows a WT 929 in the center of the sector S0 923, away from the sector boundaries. Cell 941 including three sectors S0 943, S1 945, and S2 947 shows a WT 949 near the boundary with sector S2 941, where the WT 949 receives significant downlink interference from sector S2 947.

In an embodiment of the invention, for each of these three situations, the WT sends a subset of the measured statistics to the BS 1200, in order to reduce the amount of information conveyed on the reverse link, e.g., the uplink.

In the situation shown in Figure 9 with respect to cell 901, suppose that the WT 909 in sector S0 903 receives significant interference from sector S1 905. Then a coordinated scheduler 1225 for the base station can turn off the data transmissions in sector S1 905 that interfere with the transmissions from sector S0 903 to the WT 909. Meanwhile, the transmission in sector S2 907 is coordinated so that it has the same or nearly the same transmit power Q as in sector S0. Then the SNR seen by the WT 909 will be given by

$$SNR_{S0}(Q,0,Q) = \frac{\alpha Q}{\gamma Q + N}$$

$$= \frac{SNR0(P)}{SRR1^{\gamma} \cdot SNR0(P) + \dfrac{P}{Q}}$$

in which case it is sufficient to report $SNR0(P)$ and $SRR1^{\gamma}$.

Next, for the situation shown in Figure 9 with respect to cell 921, in which the WT 929 is not near a sector boundary, it is possible to transmit on most or all sectors without causing too much interference to the WT 929. In this case, suppose the base station scheduler 1225 makes the simplifying assumption that each of the three sectors should transmit data with the same power Q. Then the SNR seen by the WT 929 for a transmission from sector S0 923 is given by

$$SNR_{S0}(Q,Q,Q) = \frac{\alpha Q}{\beta Q + \gamma Q + N}$$

$$= \frac{SNR0(P)}{SRR2 \cdot SNR0(P) + \dfrac{P}{Q}}$$

In this case, it is sufficient to report $SNR0(P)$ and $SRR2$.

Next, for the situation shown in Figure 9 with respect to cell 941, the WT 949 is located near the sector boundary with sector S2 947. Since the WT 949 receives significant interference from sector S2 947, a coordinated scheduler 1225 for the base station 1200 can turn off the corresponding data transmissions in sector S2 947. Meanwhile, suppose the transmission for sector S1 945 is scheduled with the same transmit power Q as in sector S0 943. Then the SNR seen by the WT 949 will be given by

$$SNR_{s0}(Q,Q,0) = \frac{\alpha Q}{\beta Q + N}$$

$$= \frac{SNR0(P)}{SRR1^{\beta} \cdot SNR0(P) + \dfrac{P}{Q}}$$

1067 in which case it is sufficient to report $SNR0(P)$ and $SRR1^{\beta}$.

1069   Hence, if the BS 1200 restricts the transmit powers such that they are equal to

1070 some value Q or are equal to 0, then in each of the three possible configurations, only a

1071 subset of information needs to be transmitted from the WT 1300 to the BS 1200. In

1072 particular, in one embodiment, the wireless terminal 1300 makes a decision as to which

1073 of the situations (e.g., as shown in Figure 9 cell 901, Figure 9 cell 921 and Figure 9 cell

1074 941) the WT 1300 is currently in. This information can be transmitted by the WT 1300

1075 to the BS 1200 as a two-bit Sector Boundary Indicator. The sector boundary indicator

1076 indicates wireless terminal position information relative to a sector boundary. The first

1077 bit could indicate whether the WT 1300 is on a boundary so that it is necessary to turn

1078 off the transmission in the neighboring sector. The second bit could indicate which of

1079 the two sectors causes more interference. Possible 2 bit sector boundary indicators are

1080 listed in the first column of Table 1 set forth below. The second column of Table 1

1081 indicates noise contribution information. The third column lists the control action to be

1082 taken by the BS 1200 in response to receiving the corresponding sector boundary

1083 indicator. The fourth column lists the two channel quality indictor values reported given

1084 the corresponding reported sector boundary indictor listed in the same row.

-39-

Sector Boundary Indicator	SNR	Other sectors	WT reports
00	$SNR_{S0}(Q,Q,Q)$	Transmit on all sectors	SNR0(P), SRR2
10	$SNR_{S0}(Q,0,Q)$	Turn off sector S2	SNR0(P), $SRR1^{\gamma}$
11	$SNR_{S0}(Q,Q,0)$	Turn off sector S1	SNR0(P), $SRR1^{\beta}$

TABLE 1

In this way, since the WT 1300 identifies to the base station 1200 which configuration it prefers, the WT 1300 needs to only report SNR0(P) and one of the three SRRs.

A multi-sector cell with an arbitrary number of sectors will now be discussed. In another embodiment of this invention, for the situation where there are an arbitrary number of sectors, the sectors are divided into three sector types, which we will label S0, S1 and S2. This classification into sector types is done in such a way that two adjacent sectors will not have the same type. It is assumed that for two non-adjacent sectors, the effect of interference is considered small enough as to not be significant, so that the main cause of interference is from adjacent sectors of different types. Hence it is possible to treat this situation in an analogous fashion to the case of the 3-sector cell, since the primary source of interference in each sector comes from its two neighboring sectors.

Figure 10 includes a diagram 1000 that shows the sector types for exemplary cells 1001, 1021, and 1041 with 3, 4 and 5 sectors, respectively. Cell 1001 includes a first sector S0 type sector 1003, a first sector S1 type sector 1005, and a first sector S2 type sector 1007. Cell 1021 includes a first sector S0 type sector 1023, a first sector S1

-40-

S2

1107 type sector 1025, a first sector S2 type sector 1027, and a second S1 type sector 1029.

1108 Cell 1041 includes a first sector S0 type sector 1043, a first sector S1 type sector 1045,

1109 a first sector S2 type sector 1047, a second S0 type sector 1049, and a second S1 type

1110 sector 1051. Table 2 set forth below gives an example of a plan for different numbers

1111 of sectors, where the order of the list of sector types corresponds to the order

1112 proceeding (e.g., clockwise) around the sector.

1113

Number of sectors	Sector types
1	S0
2	S0, S1
3	S0, S1, S2
4	S0, S1, S2, S1
5	S0, S1, S2, S0, S1
6	S0, S1, S2, S0, S1, S2
7	S0, S1, S2, S0, S1, S2, S1
8	S0, S1, S2, S0, S1, S2, S0, S1
9	S0, S1, S2, S0, S1, S2, S0, S1, S2

1114
1115 TABLE 2
1116

1117 Using the above sector type scheme, the scheme involving cell null pilots and

1118 sector null pilots for the case of three sectors can be used for an arbitrary number of

1119 sectors.

1120

1121 While described in the context of an OFDM system, the methods and apparatus

1122 of the present invention are applicable to a wide range of communications systems

1123 including many non-OFDM. In addition, some features are applicable to non-cellular

1124 systems.

1125

1126   In various embodiments nodes described herein are implemented using one or

1127   more modules to perform the steps corresponding to one or more methods of the

1128   present invention, for example, signal processing, message generation and/or

1129   transmission steps. Thus, in some embodiments various features of the present

1130   invention are implemented using modules. Such modules may be implemented using

1131   software, hardware or a combination of software and hardware. Many of the above

1132   described methods or method steps can be implemented using machine executable

1133   instructions, such as software, included in a machine readable medium such as a

1134   memory device, e.g., RAM, floppy disk, etc. to control a machine, e.g., general purpose

1135   computer with or without additional hardware, to implement all or portions of the above

1136   described methods, e.g., in one or more nodes. Accordingly, among other things, the

1137   present invention is directed to a machine-readable medium including machine

1138   executable instructions for causing a machine, e.g., processor and associated

1139   hardware, to perform one or more of the steps of the above-described method(s).

1140

1141   Numerous additional variations on the methods and apparatus of the present

1142   invention described above will be apparent to those skilled in the art in view of the

1143   above description of the invention. Such variations are to be considered within the

1144   scope of the invention. The methods and apparatus of the present invention may be,

1145   and in various embodiments are, used with CDMA, orthogonal frequency division

1146   multiplexing (OFDM), and/or various other types of communications techniques which

1147   may be used to provide wireless communications links between access nodes and

1148   mobile nodes. In some embodiments the access nodes are implemented as base

1149   stations which establish communications links with mobile nodes using OFDM and/or

1150   CDMA. In various embodiments the mobile nodes are implemented as notebook

1151   computers, personal data assistants (PDAs), or other portable devices including

1152   receiver/transmitter circuits and logic and/or routines, for implementing the methods of

1153   the present invention.

1154

1155   Fig. 14 illustrates the steps of an exemplary method 1400 of transmitting pilot

1156   tones in multiple sectors of a cell in a synchronized manner in accordance with the

1157 | present invention. The method starts in start node 1402 and proceeds to step 1404

1158 | wherein a current symbol time counter is initialized, e.g., to 1. Symbols are transmitted

1159 | in the exemplary system on a per symbol basis with a symbol time being the time used

1160 | to transmit one symbol along with a cyclic prefix which is normally a copy of a portion of

1161 | the transmitted symbol that is added for redundancy to protect against multipath

1162 | interference and minor symbol transmission timing errors.

1163 |

1164 | Operation proceeds from step 1404 to step 1406 wherein the transmitter is

1165 | controlled to transmit pilot symbols to be transmitted in the current symbol time in each

1166 | sector in a synchronized manner using the same tones in each sector according to a

1167 | pre-selected pilot transmission sequence, e.g., pilot tone hopping sequence, using pre-

1168 | selected transmission power levels in each sector of the cell. While pilots are

1169 | transmitted in each sector of a cell in parallel, the power level transmitted on a tone

1170 | may be some pre-selected level or zero in the case of a null tone. While the

1171 | transmission times of pilot signals in each sector are generally synchronized, slight

1172 | timing offsets between sectors may occur. Thus, each sector may actually use a

1173 | different symbol transmission time period. However, the symbol times in each sector

1174 | are sufficiently synchronized that there is substantial overlap in the symbol times used

1175 | to transmit symbols in each sector. Normally the substantial overlap is such that the

1176 | symbol transmission start times are synchronized to be within at least a period of time

1177 | corresponding to the time used to transmit the cyclic prefix sometimes called the cyclic

1178 | prefix duration. Thus, there is normally substantial overlap in the symbol times of the

1179 | different sectors even if there is not perfect overlap in symbol times.

1180 |

1181 | Which tones are used for pilot tones during a particular symbol time is

1182 | determined from the tone information 1238 included pilot hopping sequence tone

1183 | information 1234 while the power to be used on a given tone in each sector of the cell is

1184 | determined from power level information 1236.

Deleted: determine

1185 |

1186 | Once the pilot tones are transmitted for the current symbol time in step 1406

1187 | operation proceeds to step 1408 wherein a current symbol time count is incremented by

1188   1. Then in step 1410 a check is made to see if the current symbol time has reached a
1189   maximum symbol time. If the current symbol time is equal to the maximum the current
1190   symbol time is reset to 1 so that the pilot hopping sequence can begin to repeat in step
1191   1406. The periodic transmission of pilot tones continues to repeat according to the
1192   implemented pilot tone hopping sequence until base station transmission stop or some
1193   other event causes the pilot signal transmission process to be interrupted.
1194
1195   Referring now to Figs. 15-17 various exemplary pilot tone transmissions are
1196   shown along with pilot signal transmission power information.
1197
1198   In accordance with the present invention, pilot tones are transmitted using the
1199   same tones in multiple sectors of a cell at the same or substantially the same time. In
1200   various embodiments of the present invention the symbol transmission times are
1201   synchronized in the various sectors of the cell. Assuming perfect synchronization, there
1202   would be full overlap in terms of time between the pilot tones transmitted in the various
1203   sectors of a cell at any given time. Unfortunately, as noted above, precise
1204   synchronization may not be possible for a variety of reasons related to the complexity of
1205   synchronizing transmissions between different amplifiers and antennas operating at
1206   high frequencies. However, in synchronized sector implementations a substantial
1207   amount of overlap of symbol times exists between the sectors. Thus pilot
1208   transmissions can be achieved with substantial overlap making signal measurements
1209   which assume full overlap during at least a portion of each sectors symbol transmission
1210   time possible. As mentioned above, in the synchronized embodiment of the invention
1211   the difference between symbol transmission start times between the various sectors of
1212   a cell usually is less than the duration of the cyclic prefix which is normally included with
1213   transmitted symbols.
1214
1215   For purposes of discussion, it will be assumed that there is full synchronization
1216   with signals, e.g., symbols, being transmitted at the same time in a synchronized
1217   manner in each sector of a multi-sector cell. However, the above discussion makes it
1218   clear that such precise synchronization normally does not occur and is not required to

1219 | practice the invention. Thus, the transmission in each sector corresponds to a different
1220 | symbol time which may be slightly offset from the symbol time of the adjacent sector.
1221 | In accordance with the present invention, while pilot tones are transmitted in each
1222 | sector of a cell on the same set of tones in a synchronized manner, the power of the
1223 | pilot tones in different sectors of a cell are controlled to permit different signal
1224 | measurements which facilitate, in a particular sector, determining the noise contribution
1225 | from other, e.g., adjacent sector(s) as well as background noise.
1226 |
1227 | To facilitate multiple different signal measurements, multiple pilot tones may be
1228 | used during a single symbol transmission time. Alternatively, one pilot signal may be
1229 | used per symbol time with the pilot signal being assigned different power levels during
1230 | different, e.g., successive, symbol times. In such a case, the pilot signal measurements·
1231 | made during different symbol times may be used to produce the two different channel
1232 | quality indicator values which are returned to the base station in accordance with the
1233 | invention.
1234 |
1235 | Fig. 15 is a chart 1500 showing a two-sector pilot tone transmission sequence
1236 | implemented in one exemplary embodiment of the present invention. As will be
1237 | discussed below, the sequence shown in Fig. 15 can be extend to systems with N
1238 | sectors, where N is an arbitrary number greater than 1. The sequence shown in Fig. 15
1239 | is implemented for a cell which includes two sectors, sector A and sector B. The
1240 | symbol times in each sector may be slightly offset but substantially overlap and
1241 | therefore will be described as the same symbol time although actually being two slightly
1242 | different symbol times in many cases. The first column 1502 titled time refers to the
1243 | symbol time in which a tone is transmitted assuming perfect synchronization between
1244 | sectors. In one embodiment, where the same tone is used in each symbol time for pilot
1245 | signal purposes, each symbol time 1 through 4, corresponds to a different current
1246 | symbol time. The second column 1504 titled TONE lists the tone, e.g., frequency, on
1247 | which the pilot signals are transmitted. Each row corresponds to one tone. Different
1248 | rows may correspond to the same or different tones depending on the particular
1249 | implementation. For example, in cases where the first through fourth symbol times are

1250 the same current symbol time, then the first through fourth tones listed in column 1504
1251 will be different since each pilot signal requires one tone. However, in cases where the
1252 first through 4th symbol times in column 1502 correspond to different current symbol
1253 times, the tones listed in column 1504 may be the same or different.
1254
1255   As discussed above each row 1512, 1514, 1516 and 1518 corresponds to the
1256 transmission of a tone in each of the cells sectors A and B, e.g., a tone used to transmit
1257 a pilot signal. The transmission power levels in each of the sectors may be different or
1258 the same. In each case, the pilot tone transmitted at any point in time is transmitted
1259 with a pre-selected transmission power. Thus, the transmission power and tone on
1260 which a pilot signal is transmitted will be known to both the base station 1200 and
1261 wireless terminals 1300 since this information is stored in both devices and both
1262 devices know the current symbol time from timing information available in the cell. In
1263 Fig. 15, the third column 1506 lists the pilot signal transmission power level for the pilot
1264 signal transmitted in sector A using the tone to which the particular row corresponds.
1265 Similarly the fourth column 1508 lists the pilot signal transmission power level for the
1266 pilot signal transmitted in sector B using the tone to which the particular row
1267 corresponds. Column 1510 is included for purposes of explaining a 3 sector   **Deleted:** Each column 150
1268 embodiment later but is not used in the two sector implementation being described in
1269 regard to Fig. 15.
1270
1271   Each rectangle in column 1506 and 1508 represents a step of transmitting a pilot
1272 signal in the indicated sector at the general symbol time indicated in column 1502 using
1273 the tone indicated in column 1504. In practice, the tones are transmitted at slightly
1274 different symbol times in each of sectors A and B, e.g., first and second symbol times
1275 which correspond substantially to the symbol time listed in column 1502. A 1 is used to
1276 indicate a non-zero pilot having a first pre-selected transmission power while a zero is
1277 used to indicate transmission of a null tone, e.g., a pilot signal with transmitted with zero
1278 power.
1279

1280	Row 1512 shows that at symbol time 1, using tone 1, a 1 pilot signal is
1281	transmitted in sector A while a NULL pilot signal is transmitted in sector B. This makes
1282	it possible to measure the contribution of inter-sector interference in sector B caused by
1283	sector A transmission on the same tone. It also allows sector A to make accurate
1284	measurements of the attenuation in sector A without the presence of interference due
1285	to sector B transmission. Row 1514 corresponds to symbol time 2 wherein tone 2 is
1286	used to transmit a NULL tone in sector A and a 1 pilot signal in sector B. This allows
1287	sector A to determine the amount of signal interference due to sector B transmission on
1288	the same tone. Row 1516 corresponds to symbol time 3 wherein tone 3 is used to
1289	transmit a NULL pilot signal in both sectors A and B making general background noise
1290	measurements possible on tone 3. Row 1518 corresponds to symbol time 4 wherein
1291	tone 4 is used in both sectors A and B to transmit 1 pilot signals. In such a case each
1292	sector can measure the effect of having a signal transmitted with the same non-zero
1293	power level in each of sectors A and B at the same time. Normally pilot signals are
1294	transmitted in accordance with both the first and second rows 1512, 1514 of Fig. 15 and
1295	at least one of rows 1516 and 1518 in order to provide a wireless terminal to make
1296	sufficient signal measurements which required as input to the two different functions
1297	used to generate the first and second channel quality indicator values that are feedback
1298	to the base station 1200 in accordance with one feature of the invention.
1299	
1300	Fig. 16 is a chart 1600 illustrating an exemplary pilot tone transmission
1301	sequence for a three sector system. As in the Fig. 15 example, the first column 1602
1302	corresponds to symbol transmission time, the second column 1604 corresponds to tone
1303	while columns 1606, 1608 and 1610 indicate pilot signal transmissions in each of three
1304	sectors A, B and C of a cell, respectively. Thus, as in the Fig. 15 example, each
1305	rectangle of column 1606, 1608 and 1610 which corresponds to one of the first through
1306	fifth rows, 1612, 1614, 1616, 1618, 1620 represents the step of transmitting a pilot
1307	signal on the indicated tone in the indicated sector. While the tones used in each row
1308	are the same in each sector, as discussed above, when each of the symbol times
1309	corresponds to the same current symbol time, the each of the first through fifth tones

Deleted: illustrates

1310 will be different. However, when each of the first through fifth symbol times are different

1311 the first through fifth tones may be the same or different.

1312

1313   Note that in the Fig. 16 implementation, at least one pilot signal is transmitted for

1314 each sector with a null pilot being transmitted on the same tone in an adjoining sector.

1315 Also note the use in row 1620 of what has been described as cell null which facilitates

1316 background noise measurements.

1317

1318   Fig. 17 is a chart 1700 showing a three sector implementation similar to Fig. 16

1319 with the pilots transmitted in each sector being described in a more general manner in

1320 terms of power levels. The transmission of 15 pilots P1 through P15 are shown in the

1321 Fig. 17 embodiment with each pilot being transmitted at a different symbol time in the

1322 case where each row corresponds to a different transmission symbol period. In the

1323 case where each of the listed signals are to be transmitted in the same symbol time,

1324 three different symbol times are shown, with the transmission time of each sector being

1325 slightly different but corresponding to substantially the same symbol time as used in the

1326 other sectors.

1327

1328   As in the Fig. 15 and 16 examples the pilots of each row 1712, 1714, 1716,

1329 1718, 1720 are transmitted using the same tone but different rows may correspond to

1330 different tones. While being shown as being transmitted at 5 different symbol times as

1331 listed in the first column 1702, when variations in sector transmission times is taken into

1332 consideration each rectangle listed on the heading Sector may actually correspond to a

1333 different symbol time with the symbol times of each row substantially overlapping and

1334 being identical in the case of precise synchronization. The power level of each of the

1335 first through 15th pilots P1 through P15 are represented in parenthesis, e.g., the

1336 transmission power for P1 is p1. While in some cases such as in the Fig. 16 example

1337 two different power levels are supported, multiple known power levels may be

1338 supported. The last row 1720 of Fig. 17 represents the transmission of a NULL pilot

1339 signal using tone 5 in each of sectors A, B and C according the power level of these

1340 pilot signals is 0 in each case.

1341

1342   Fig. 18 illustrates a chart 1750 showing the transmission of signals on 10

1343   different tones during a single symbol transmission time period. In the Fig. 17

1344   implementation the 0 is used to represent a NULL pilot signal, while a 1 is used to

1345   represent a pilot at a single known non-zero transmission power level which is normally

1346   higher than the power level at which data is transmitted. D is used in the chart 1750 to

1347   illustrate the transmission of data in one of the sectors A, B and C. The data signal D is

1348   usually transmitted on the tone at a power level lower than the pilot signal level 1 and

1349   therefore may not cause significant interference with the pilot in the neighboring sector.

1350   Data is normally transmitted in each of the sectors on additional tones not shown in Fig.

1351   17 during the illustrated symbol time. In the OFDM embodiment of the present

1352   invention, in a given sector such additional data tones do not interfere with the pilot

1353   tones since they are orthogonal to the tones used to transmit pilot signals. Fig. 19

1354   illustrates a method 1800 of operating a wireless terminal to process pilots signals

1355   received from a base station 1200, which were transmitted in accordance with the

1356   present invention. The received pilot signals may be pilot signals that were transmitted

1357   with known different transmission power levels allowing the receiving device to make

1358   various signal measurements and computations useful for determining various noise

1359   contributions, e.g., background noise as well as inter-sector interference.

1360

1361   The method 1800 starts in start node 1802 and proceeds along two processing

1362   paths beginning with steps 1804 and 1808, respectively. The two processing paths

1363   may be implemented in parallel, e.g., in the case where multiple pilot signals with

1364   different transmission power levels are transmitted during a single symbol time, or in

1365   series, e.g., in the case where pilots are transmitted sequentially using the same tone

1366   but different power levels during different symbol transmission times.

1367

1368   In step 1804, the wireless terminal 1300 measures at least one of an amplitude

1369   and a phase of a first pilot signal that was transmitted with transmission power P1 to

1370   produce a first measured signal value. The first measured signal value is then used in

1371   step 1806. In step 1806, a first channel quality indicator value is generated from the

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1372	first measured signal value according to a first function, f1, which uses at least said first
1373	measured signal value as an input. The first channel quality indicator value generated
1374	by function f1 may be, for example, an SNR value or a signal power value,
1375	corresponding to said first received pilot signal. Function f1 may use other signal
1376	measurements and/or other information as inputs in addition to the first measured
1377	signal value when generating the first channel quality indicator value. Operation
1378	proceeds from step 1806 to step 1812.
1379	
1380	In step 1808, which may be performed in parallel with step 1804 in some
1381	embodiments, the wireless terminal 1300 measures at least one of an amplitude and a
1382	phase of a second pilot signal which was transmitted with transmission power P2,
1383	where P2 is different from P1. The measurement produces a second measured signal
1384	value which is then used in step 1810. In step 1810 a second channel quality indicator
1385	value is generated from the second measured signal value according to a second
1386	function, f2, which uses the second measured signal value as an input. The second
1387	function is different from said first function and uses at least the second measured
1388	signal value as an input but may also use other signal measurements as inputs as well.
1389	In some embodiments, the second channel quality indicator value generated by the
1390	second function is an SNR value corresponding to the second pilot signal while in other
1391	embodiments it is a signal power value, e.g., an indicator of received signal power,
1392	corresponding to the second pilot signal. Operation proceeds from step 1810 to step
1393	1812.
1394	
1395	In step 1812, the wireless terminal 1300 determines the location of the wireless
1396	terminal relative to one or more sector boundaries from measured signal values and/or
1397	other boundary location indicator value information discussed above. Using the relative
1398	boundary location and/or other information generated in step 1812, in step 1814 the
1399	wireless terminal 1300 generates a boundary location indicator value 1814, e.g., having
1400	a value corresponding to one of the values shown in column 1 of Table 2. With the first
1401	and second channel quality values from steps 1806 and 1810, and the boundary

location indicator value from step 1814, operation proceeds to transmit step 1816 wherein the generated information is transmitted back to the base station 1200.

Step 1816 involves the transmission of the first and second channel quality indicator values and the boundary location indicator value, e.g., as part of one or more messages. Two alternative processing paths are shown with a single processing path being used in any particular implementation. The first processing path beginning with sub-step 1820 and ending with 1826 represents the case where various information is included in a single message. The second processing path beginning with step 1830 and ending with step 1840 corresponds to the case where different messages are used to transmit each of the various values. Messages in this context are to be interpreted broadly and include signals which convey the particular values to be communicated.

In step 1820, the first channel quality indicator value is incorporated into a first message. Then, in step 1822 the second channel quality indicator value is incorporated into the first message. Next, in step 1824 the boundary location indicator value is incorporated into the first message. The first message is then communicated to the base station 1200 in step 1826, e.g., by transmitting the first message over a wireless communication link. This is done in various embodiments using one or more dedicated time slots of a control channel used to report channel quality and/or other feedback information from wireless terminals to the base station 1200. As a result of the dedication of the time slot to the wireless terminal using it to report channel quality and other information, other wireless terminals or devices in the sector will not use the time slot. Thus, through the use of dedicated time slots transmission conflicts are avoided. Furthermore, given that the channel is dedicated to communicating particular control information, the values may be generated and transmitted in the time slots without having to send headers or other information indicating what the meaning of the transmitted values are. That is, the base station 1200 knows that values transmitted in the utilized control channel are to have a certain pre-selected format and represent, e.g., first and second channel quality indicator values followed by a two bit boundary location indicator value. Thus, the amount of overhead, e.g., header overhead, used to

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1433 transmit such messages and/or values can be minimized. With the transmission of the

1434 generated values having been completed in step 1826, operation returns to steps 1804

1435 and 1808 wherein signal measurements are made on new pilot signals with the

1436 feedback process continuing to repeat over time.

1437

1438   In step 1830, which corresponds to the alternate value transmission path shown

1439 in step 1816, the first channel quality indicator value is incorporated into a first

1440 message, e.g., a signal, which is then transmitted to the base station in step 1832.

1441 Then, in step 1834 the second channel quality indicator value is incorporated into a

1442 second message, e.g., signal, which is transmitted in step 1836. The boundary location

1443 indicator value is incorporated in step 1838 into a third message, which is then

1444 transmitted to the base station 1200 in step 1840. As in the case of the combined

1445 message transmitted in step 8126, the individual messages transmitted in steps 1832,

1446 1836 and 1840 may be transmitted using dedicated segments of a control channel

1447 dedicated to the communication of feedback information. Operation proceeds from

1448 step 1840 to steps 1804 and 1808 with the processing of generating the channel

1449 feedback information and reporting the information to the base station 1200 repeating

1450 over time.

1451

1452   Figure 20 shows a flowchart 1900 illustrating a method of operating base station

1453 (BS) 1200 in accordance with the present invention, e.g., to transmit pilot tones and to

1454 receive and process feedback information to determine the power level at which to

1455 transmit data signals. The method starts with step 1902 where the base station 1200 is

1456 powered on and operational. In step 1904, base station's transmitter 1204, coupled to

1457 a multi-sector antenna 1205, transmits pilot signals into each sector, e.g. S0 1106, S1   Deleted: is

1458 1108, S2 1110 of a multi-sector cell, e.g., 1104 at the same time in a synchronized

1459 manner using predetermined power levels and tones such that the transmission of the

1460 pilot tones into each of the sectors 1106, 1108, 1110 of the cell 1104 use the same set

1461 of tones and are transmitted at substantially the same time in each of the sectors 1106,

1462 1108, 1110. The transmission of pilot tones in step 1904 is performed under the

1463 direction of the pilot signal generation and transmission control routine 1230 using pilot

tone power level info 1236 and tone info 1238. Operation proceeds to step 1906 where BS 1200 receives messages from at least one wireless terminal (WT) 1300 including, e.g., a set of channel quality indicator values, e.g., first and second channel quality indicator values, and sector boundary position information. The messages are received under the direction of the received signal processing routine 1260 included in base station 1200. In step 1908, the base station, under the direction of channel quality indicator value extraction module 1262 extracts at least two different channel quality indicator values 1250, e.g., from a single message or from multiple messages received from a wireless terminal 1300. In some embodiments each channel quality indicator value is in a separate message. In other embodiments multiple channel quality indicator values are include in a single message from a WT 1300. Next, in step 1910, the base station 1200, under control of position information extraction module 1264, extracts location information from received messages, e.g., boundary position indicator value, indicating the position of a wireless terminal 1300 relative to a boundary in a multi-sector cell. This location information may have been transmitted by WT 1300 in a separate message or may have been included in a message including channel quality indicator values. This location information may identify whether the WT 1300 is near a sector boundary, and identify which sector boundary, e.g., identify the adjacent sector from which a higher level of transmission power dependent interference is being received. Sector boundary information extracted from received messages is stored in sector boundary position information 1252 in BS 1200.

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Proceeding to step 1912, the base station 1200, under the direction of transmission power calculation routine 1226 calculates from at least first and second channel quality indicator values 1250 an amount of transmission power required to achieve a desired signal to noise ratio at said wireless terminal 1300 from which said first and second channel quality indicator values 1250 were received. In step 1914, the base station scheduler module 1225 operates to make scheduling decisions for the wireless terminals 1300. In sub-step 1916, the base station scheduler 1225 makes decisions for the WT 1300 based on determined SNR, e.g., BS 1200 schedules segments to the WT 1300 on channels with transmission power levels that will result in

a received SNR of the WT 1300 exceeding the minimum acceptable level for the data rate and coding scheme used. In sub-step 1918, the BS 1200 scheduler 1225 makes decisions for the WT 1300 based on sector boundary position information 1252, e.g., for a WT 1300 identified as being near a sector boundary; base station 1200 assigns channel segments to the WT 1300, with corresponding channel segments in the adjacent sector having no transmission power. Proceeding to step 1920, BS 1200 transmitter 1205 transmits signal, which may include, e.g., user data 1244 that has been encoded by encoder 1214, under direction of signaling routine 1228 at a scheduled time to said WT 1300 using transmission power determined from said at least two channel quality indicator values 1250 that were received.

Operation proceeds from step 1920 back to step 1904 and the method is repeated. Base station 1200 will be repeating the transmitting pilot signals in a synchronized manner into each sector of the multi-sector cell in step 1904, on a regular basis. However, different wireless terminals 1300, may send messages including set of channel quality indicator values 1250 and sector boundary position information 1252 at different times and/or different rates depending on factors such as the state of operation the wireless terminal is in, e.g., on, hold, sleep.

The invention is directed to, among other things, machine readable medium such as memory, compact disks, etc. including machine executable instructions, e.g., software modules or commands, for controlling a processor or other device to perform processing in accordance with one or more of the various method steps of the invention. Various features of the methods and apparatus of the invention can be used in a wide range of communications systems including, but not being limited to, OFDM, CDMA and other types of communications systems.

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